Despite continuous improvements in the field of energy efficiency, global power generation is expected to almost double by 2040 (EIA, 2013). Although the lion’s share will still be based on fossil fuels, generation from renewable energy sources will increase both in absolute and relative numbers. The highest annual growth rates are assumed to be wind and solar power, at 4.7% and 7.1% respectively (EIA, 2013). However, researchers and scientists are in search of a “black swan” for the energy sector. One candidate is the field of Airborne Wind Energy (AWE). Significant material savings in combination with stronger and more persistent winds at higher altitudes are two major reasons why people see the potential for low-cost energy (Archer, C. L., Delle Monache, L., & Rife, D. L., 2014). It is not only the technical feasibility that plays an important role for successful implementation, but also the economic feasibility. In the context of the energy landscape and more specifically power generation, the single-most important parameter is the Levelized Cost of Electricity (LCOE). In other words: how much does it cost to produce electricity over a system’s lifetime?

RESEARCH AT TU DELFT
From the various existing AWE concepts, the Kite Power research group at TU Delft focuses on a so-called pumping kite power system (KPS). It uses an inflated wing equipped with a remote-controlled cable robot, the kite control unit, which connects kite and ground station via a tether. All system components are depicted in Figure 1. The drum-generator unit converts the mechanical traction power into electrical power. One pumping cycle is divided into a traction and retraction phase. The ability to de-power the kite, while reeling-in, makes it possible to generate net energy over a full cycle. With its maiden flight in January 2010, the 20kW technology demonstrator successfully proved the working principle. Successive improvements lead to the key milestone of automatic operation in June 2012. Eventually the goal is to scale a KPS to reach sizes of more than 500kW electrical output, suitable for electricity production at utility scale. To this end, the research objective of the graduation project was defined around the aspect of scaling and economics of a KPS. What is more, optimization problems were defined in order to both operate the system at optimal settings and design the components in the most beneficial way, meaning the lowest LCOE.

METHODOLOGY
Since current AWE prototypes are well below 100kW power output, a physical reference system did not exist. Scaling had to be done on the basis of analytical frameworks, empirical data and numerical optimization.
simulations. For all system components such as kite, tether and ground station, separate scaling laws were defined for both the physical parameters as well as the respective cost functions. The optimization problem regarding the operation of the KPS was defined for five operational parameters, which were found suitable for the purpose of estimating the power output of the system: These are the minimum and maximum tether length, the set values for the tether force for the reel-in and reel-out phases as well as the tether elevation angle during the traction phase. For each wind speed, a separate optimization had to be carried out.

Apart from the optimization of operational parameters, the research goal was to identify the ideal system configuration. For this purpose, various component combinations were compared with each other by way of comparing the LCOE for a given location and the (annual) wind data was approximated using Weibull distributions. Systems were compared for kites with sizes ranging from 20m² to 400m² and generator sizes ranging from 30kW to 500kW.

The fact that the optimization of operational parameters and the optimization of the system configuration are coupled requires a computationally expensive approach. In the developed model, a nested approach is used, meaning that the optimization problem for the system configuration is wrapped around the optimization of operational parameters, which have to be found separately for each configuration and range of wind speeds.

APPLICATION AND RESULTS

The developed computational model was applied for two cases: small-scale systems for the deployment in remote off-grid locations and utility-scale units for the European market. Considering the former, the optimum system design was found to be a 30kW unit in combination with a 21m² kite, which results in a LCOE of approximately 250€/MWh. Due to high prices of electricity in off-grid situations this figure is cost competitive against existing solutions such as diesel generators. However, major non-technical barriers were identified, which need to be taken into account when formulating a business case of kite power implementation in remote areas that are often located in developing Countries. One of which is the aspect of financing renewable energy technologies, which generally require high initial investments.

Secondly, a large-scale unit was analyzed consisting of a 350kW generator using a 208m² kite. In Figure 2, the power curve of such a system is shown. Similarly to a conventional wind turbine, the x-axis depicts the wind speed at ground level, in this case 10m height. One can observe that the losses of the system increase for increasing wind speeds. For more information on the aspect of power conversion of kite power systems, one is referred to the literature; in October 2013, the first comprehensive textbook with 36 contributed chapters on the emerging Airborne Wind Energy sector was published (Ahrens, U., Diehl, M., Schmehl, R., 2013).

In comparison with the small-scale system the LCOE decreases to 60-80€/MWh. It must be mentioned that these numbers assume a system that is built in three to four years time. Due to advancements in the fields of material research (mainly kite and tether) alongside with design improvements of components and optimized system operation, these figures are expected to decrease further.

CONCLUSIONS

Based on the outcome of the simulation results using the developed model, the LCOE of a KPS in the near future is competitive in both analyzed cases of off-grid and utility-scale situations. Further efforts preceding a commercial implementation of the technology on the European market include the successful demonstration of long-term operation and a fully automated launch and retrieval system. What is more, critical assumptions made in the model, e.g. keeping the aerodynamic properties constant while scaling up, need to be verified and validated using measurement data from test flights in the future.

THE ROAD AHEAD

Starting in the summer of 2014, a joint project in collaboration with the University of Applied Sciences Karlsruhe will set out with the goal of achieving 24 hours continuous flight-operation within one year. For more information one can best follow the news feed of the research group (www.kitepower.eu).

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References


Figure 1. System components of the 20kW technology demonstrator of the Kite Power research group at TU Delft.

Figure 2. Mechanical and electrical power curve of a utility-scale kite power system